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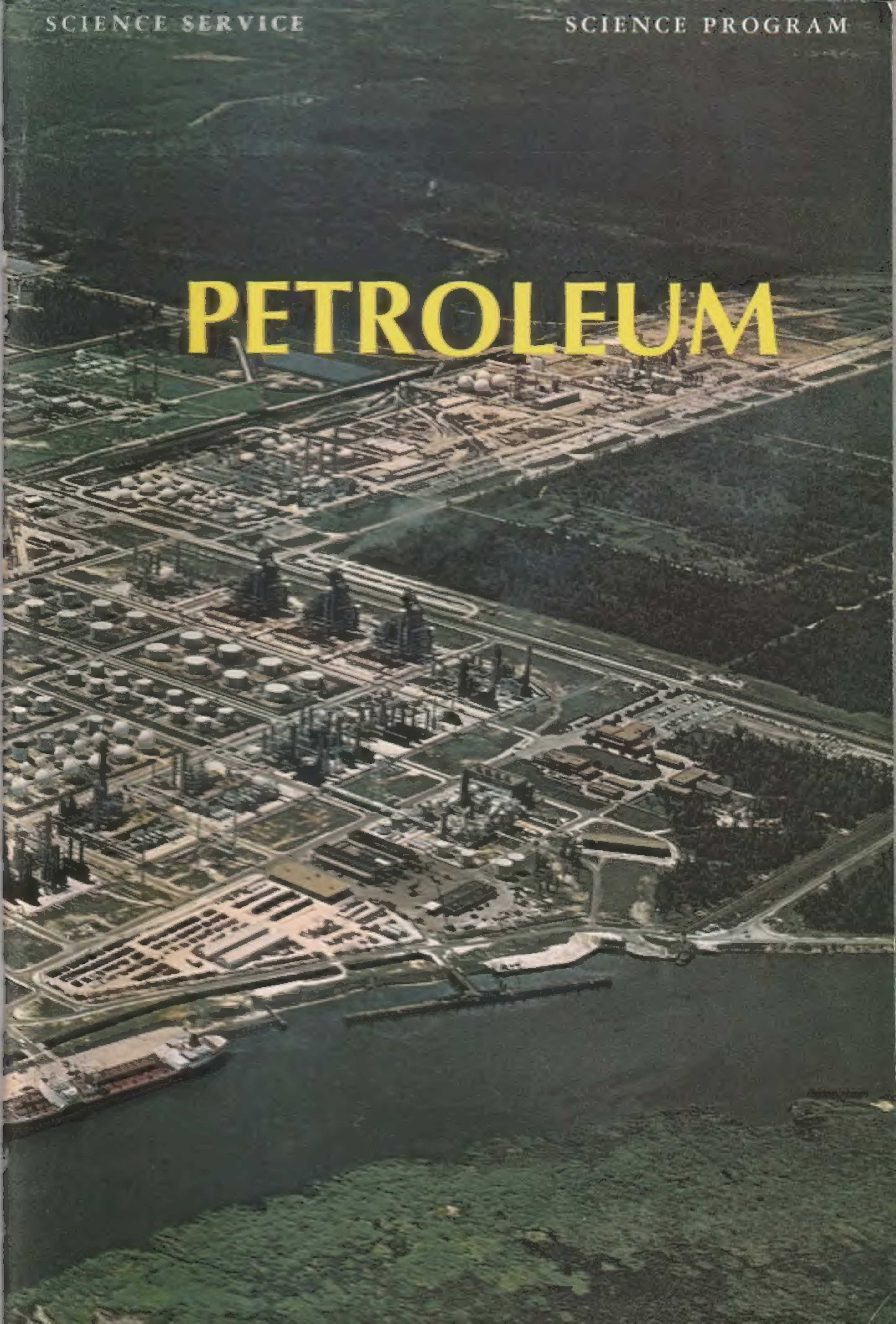
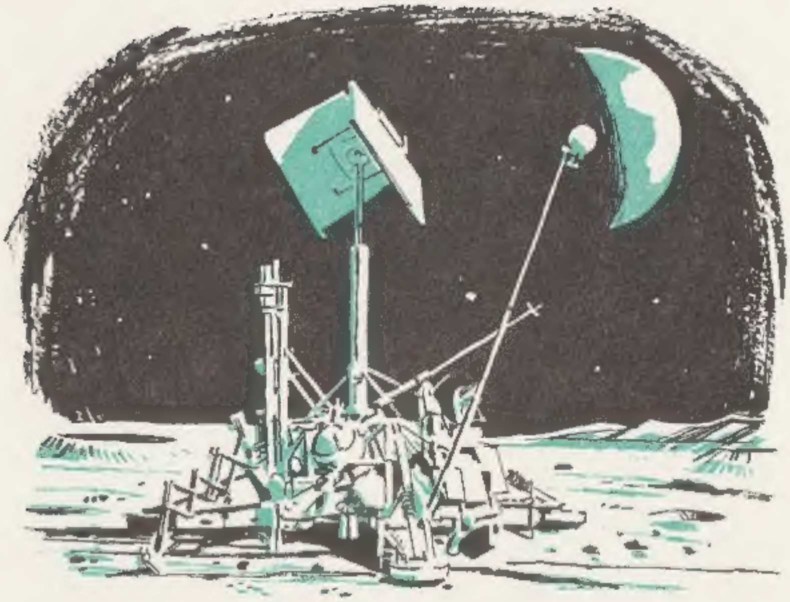
PETROLEUM





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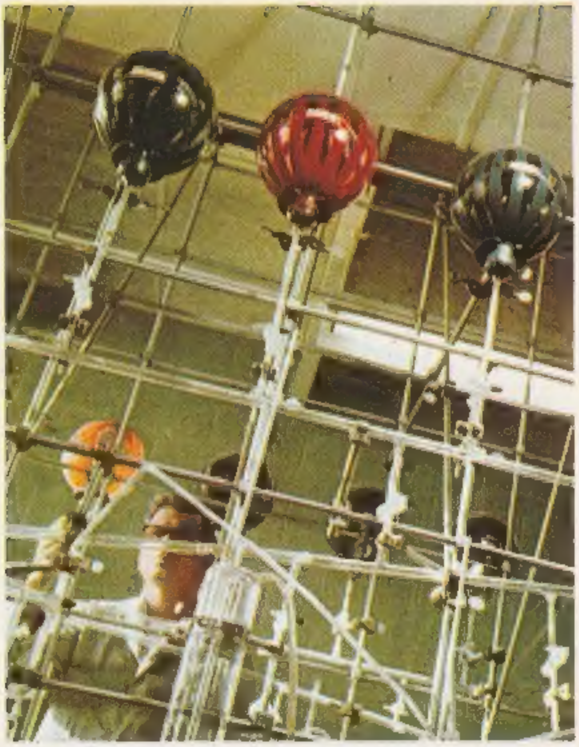
The Great Mystery of Petroleum

A HUNDRED YEARS AGO, the earth captured a rock from space—a meteorite which crashed and shattered near the small town of Orgeuil in France. People witnessed its fall and picked up pieces. Museums acquired some of them. Eventually a fragment of the Orgeuil meteorite found its way to New York and into the laboratory of a team of scientists who had decided to probe its insides.

The scientists selected a slice from the very heart of the meteorite. They wanted to be sure that what they were about to test was really matter from another world, uncontaminated by contact with anything on earth. One of the tools they used was a mass spectrograph, a device capable of detecting the smallest traces of elements and chemical compounds.

After due time the scientists made an announcement which caused a sensation among experts and laymen. They said that inside the meteorite they had found a "waxlike substance" which, sealed within the rock, had presumably reached the earth after a trip from somewhere in space. The most startling fact was that the waxlike substance appeared to have none of the strange qualities sometimes associated with people's ideas about extraterrestrial life; it did not seem to belong to a planet inhabited by little green men but rather to our own world. The waxlike substance resembled a material produced by many insects and plants—for instance the waxy coating of an apple. It also resembled some of the hydrocarbons found in petroleum. It had all the subtle chemical earmarks pointing to an organic origin.

The conclusion seemed obvious. If the core of the Orgeuil meteorite had really never been touched by anything on earth and if it had not been invaded by bacteria from French soil or the dust of a museum (this possibility is still being discussed by scientists), some form of life must have existed in whatever part of the universe the Orgeuil meteorite had started on its voyage. Some form of life must have existed, or, possibly, petroleum. The two are not very far apart. The same molecules might be found in either.



1. RESEARCH LABORATORY

A research scientist measures the surface area of carbon black —a derivative of petroleum used in pigments for paints and inks.

This is no accident. All life—plants, and animals which live on plants—is dependent on the energy of sunlight. The energy of sunlight makes it possible for plants to use carbon dioxide and water to make food which then becomes part of their living matter. Sunlight is needed for this process; so are atoms of hydrogen and carbon.

That much is certain. It is also certain that many billions of barrels of petroleum are in the ground. (1 barrel=42 gallons) Petroleum is often discovered in places where we know or assume that life once existed: in or near sediments covering the bottoms of ancient seas. Many of its molecules are identical with those of living cells. Yet there is a gap in our knowledge. No one has ever witnessed the transformation of organic matter into petroleum or shown in a laboratory how this was accomplished by nature. But although there is no absolute proof, the evidence

is convincing; today most scientists believe that petroleum owes its origin to living matter.

They are still discussing the "how". According to one version, petroleum was created in former periods of the earth's history when the remnants of plants and innumerable minute animals sank to the bottom

of shallow seas. Mud covered them; mud, sand, silt, and more plants and animals, thoroughly mixed, built layer upon layer so that finally the lowest layers were buried under sediments thousands of feet thick.

The weight and perhaps stresses in the crust of the earth squeezed, deformed, crushed and compressed the sediments. Heat, generated by the immense pressure, broke the bonds between the organic molecules and forced them into new combinations—the bewildering variety of hydrocarbon molecules which make up petroleum.

Others believe that the molecular changes were brought about by chemical action and maybe by the natural radioactivity of the earth. Still other scientists think that bacteria, feasting on decaying organic matter, contributed their own hydrogen to the carbon atoms they found, and the result was petroleum. Petroleum may even have been formed by two or more of these processes.

Almost all petroleum is millions of years old. However, there seems to be evidence of continuous creation of petroleum, and very small quantities are possibly being formed even now.

At any rate, hardly any petroleum geologist today doubts the organic origin of petroleum. The external shapes of life are no longer recognizable. However, the force that once created and nourished life is still there: the energy of sunlight. It is locked in every one of the hydrocarbon molecules in billions of barrels of petroleum.

Putting "Crude Oil" to Work

WE HAVE LEARNED TO USE this energy in many ways. We burn petroleum or, rather, certain groups of its molecules, to run cars, diesel locomotives and planes, and to heat our homes. We use other groups to make medicines, to kill mosquitoes, to pave streets, to manufacture a myriad of cosmetics or plastics or to spray apple trees so that no apple falls to the ground before it is ripe.

These uses are quite different from one another. What petroleum will accomplish is largely dependent on exactly what group or groups of its molecules are used. The choice is enormous. Each petroleum deposit contains a mixture of thousands or even hundreds of thousands of hydrocarbons; and the mixture in one petroleum deposit is different from that in any other.

These mixtures certainly do not look alike. "Crude oil", as petroleum is often called in its natural form, may be without hue—or pitch black, amber, brown or green. It may flow like water, or creep like molasses.

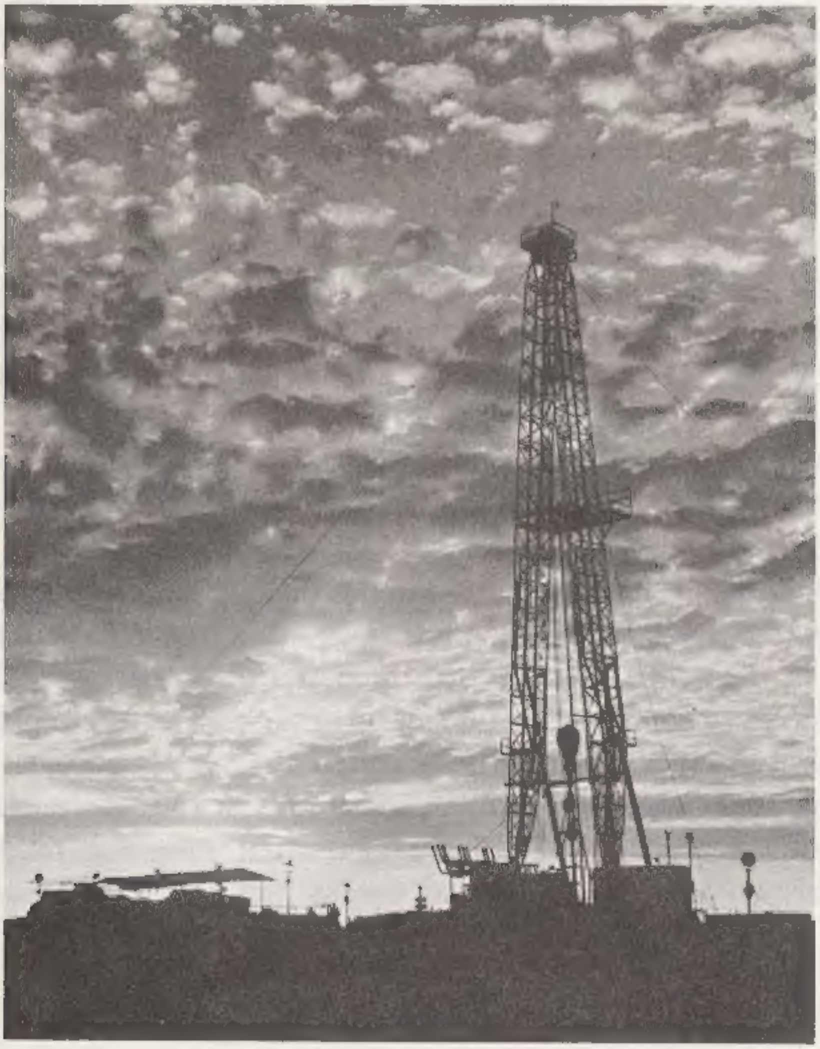
In 1927 a group of scientists set out to identify the hydrocarbons in *one* petroleum taken from a field in Oklahoma. Four decades later they had worked out the chemical structures of 264 "easy" hydrocarbons. Some are present in petroleum in quantities up to 2.3 per cent: others appear only as traces. Their boiling points range from —256° F. to +887° F., their names run from methane or benzene to cis-Decahydronaphthalene.

This is only the beginning of the project. The identification of hundreds of thousands of more "difficult" hydrocarbons in this one petroleum taken from an Oklahoma field still lies ahead.

Theoretically millions of combinations are possible. The basic unit—*one carbon atom linked with four hydrogen atoms*—is found in marsh gas or methane. But dozens of carbon atoms can be linked with dozens

of hydrogen atoms. The carbon atoms can be arranged in straight chains or in branched chains, in rings, in double linkage with other carbon atoms or in hexagons. The number of atoms and the pattern in which they are linked usually determine the chemical properties of the product. For instance, ordinary (or "normal") butane (C_4H_{10}) has four carbon atoms arranged in a straight chain. When only three of them are in a straight chain and the fourth in a "branch", the chemical formula still is C_4H_{10}, but the molecule has acquired different characteristics and is known as isobutane, used in making high-octane gasoline.

Hydrocarbons are not all the same. It is one of the jobs of the petroleum chemist to juggle the number of atoms and their patterns until he has found the most desirable arrangement.



Where Oil Is Found

ORDINARILY, PEOPLE DO NOT SPEND too much time thinking about the place where petroleum might be before it reaches the surface. Sometimes they are under the impression that once upon a time nature must have stored the liquid in subterranean caverns and that it has been resting there ever since, and all of it would continue to rest there if it were not tapped by oil wells. Or people have a vague notion of great rivers of oil flowing underground for hundreds of miles. They also visualize vast underground "oil belts". Oil pools—the word is often used by oilmen in a different context—would be just that: ponds or maybe even lakes which happen to be underground and are filled with oil rather than water.

For a long time, oilmen themselves did not have too much information about the subject. Now they have learned that there are no underground oil rivers or lakes. There are no oil belts. Actually, the word petroleum comes from two Latin words—*petra,* meaning rock, and *oleum,* meaning oil. That name was given after men discovered that where oil pools exist, they are in formations of porous rock.

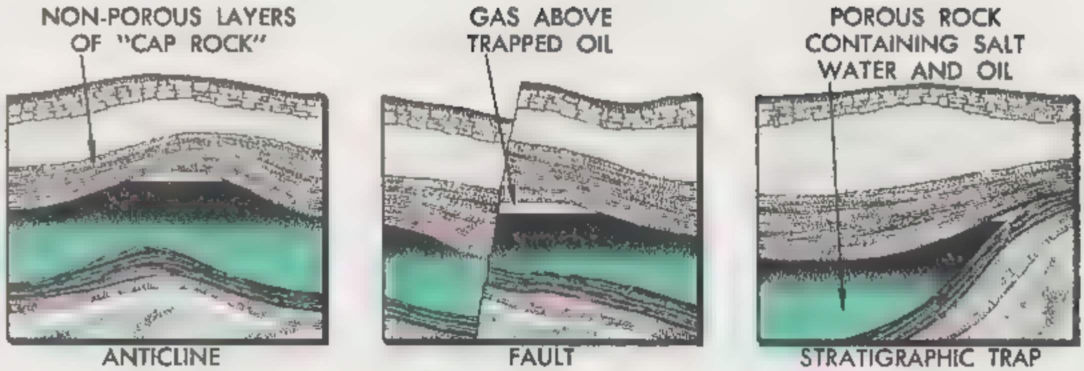
This is how this probably happened: Oil-rich mud was squeezed by the weight of accumulating sediment. Oil, gas and water were forced into the pores of rocks such as sandstone. The oil did not stay there. Being lighter than water, it rose above the water with which the rock was saturated. It continued to move from one porous layer to the next, until it was blocked by a rock layer with pores so small that no oil could enter. Under this barrier it was trapped.

Then the rocks shifted. Time and again the earth heaved and buckled. Here and there volcanoes spread blankets of lava. Mountains rose on plains. Ancient sea bottoms became part of the dry land of continents. When mud and silt had been deposited on the sea floors, their layers had originally been nearly horizontal. Now they were folded and broken by stresses in the crust of the earth, tilted sideways and sometimes turned upside down by tremors and volcanic eruptions. The oil remained buoyant, of course. It still tried to rise through the rock wherever it could.

Every now and then the oil did succeed in reaching the surface. This is the origin of oil seepages. They are somewhat rare but they do occur, forming a brown or greenish film on creeks and ponds in various parts of

(*Right*) Petroleum tar bubbles to the surface of a California pond.

TYPICAL OIL TRAPS



the world. Long ago, men discovered that the surface oil could be put to various uses. Two thousand years ago, Greek colonists in Sicily had petroleum lamps. To the ancient Persians petroleum was the source that nourished their sacred fire. American Indians rubbed it on their skin. But seepages never occurred in what we would call commercial quantities. Most petroleum remained trapped, sealed off by non-porous layers of rock.

We know now that there are three main types of traps where non-porous rock blocks the upward passage of oil. The first is the *anticline,* an oil-bearing layer curving upward so that it forms an arch; the oil collects, and is stopped, under its apex. The second type is the *geological fault,* a fracture in the earth's crust. Rock strata have slipped somewhat in the manner of a sandwich, one-half of which has slid over the edge of the plate; one side of a porous layer is now resting against a non-porous layer, and here the oil is stopped. The third type is the so-called *stratigraphic trap*. Here the oil-bearing stratum gets thinner and thinner and finally peters out between two non-porous layers. Again, to the petroleum this is the end of the upward road. There is no escape except through erosion of the non-porous barrier, which may take millions of years, or through fractures caused by earthquakes or lesser earth movements, or through an oildriller's well.

These are typical "oil sands" ("sand" in the oilmen's language means rock). They were the clays and silts and sands of ancient sea floors which became the shales, dolomites, limestones and sandstones of today —the more common oil-bearing sedimentary rocks resting on the so-

called "basement rocks" such as granite. The question why oil occasionally occurs in basement rocks has not yet been answered to the satisfaction of all petroleum geologists. Some of the many explanations are highly original. For instance, it has been claimed that the heat differential between the oceans and the continents sets up convection currents which will eventually inject petroleum molecules into granite.

Many wells have tapped the oil accumulation found in anticlines, along faults and in stratigraphic traps. There are more than 630,000 oil wells in the United States alone. But what may be the largest oil deposits by far are still untapped. They are on the surface or close to the surface. But the hydrocarbons are clasped tenaciously by rocks from which they can be dislodged only by heating the rocks or crushing them or by other costly processes. These deposits are in the Athabasca tar sands of Alberta and in the shale formations of Colorado, Wyoming and Utah—the "mountains of oil".

The Athabasca tar sands probably contain 300 billion barrels of recoverable hydrocarbons chiefly in the form of bitumen from which crude oil can be processed. Up to 40 billion barrels may be economically accessible in the United States. Together, they are roughly equivalent to the total U.S. proved reserves of liquid hydrocarbons (crude oil and natural gas liquids). The potential yields of shale oil are even more startling. The deposits in the United States are estimated to contain more than one trillion barrels of recoverable oil. This is almost twelve times as much as the United States has produced in the last 100 years.

The Great Search for Oil

GETTING THE OIL OUT OF THE GROUND has become expensive. Oilmen have to sink wells to ever greater depths and the cost per foot increases with the distance from the surface. The average cost of drilling an oil well today is $95,000. Offshore wells cost eight times as much. One well on Alaska's North Slope, even though it was on land, cost $5.9 million—and it was dry. Early in 1972, oilmen in Oklahoma sank the deepest well ever—30,005 feet.

But the first man to drill an oil well did not have to go far at all. He was Edwin L. Drake, the retired railway conductor who later became known as Colonel Drake. On 27 August, 1859, in Titusville, Pennsylvania, his drill hit an oil-bearing stratum at a depth of sixty-nine and one-half feet. He and his backers knew, or thought they knew, where to

The original Drake well, shown in an 1861 photograph.

look for oil. An oil seepage had been spotted on the bank of a creek. The surface oil must have come from someplace below.

Others followed the same clues: seepages and creeks. But all known seepages had soon been explored, and the creeks were thoroughly unreliable. For some time, the search for oil was conducted on a hit-or-miss basis supported by very little factual evidence. Oilmen did begin to study surface formations but were as yet unable to reach useful conclusions. Others followed hunches and even dreams. Some hired dowsers; the twitching of forked sticks in their hands was supposed to guide prospectors in their search.

Gradually oilmen did gain useful experience of a sort, although at first the theory behind it was shaky. For instance, they learned to avoid

drilling sites near sawmills and to favor sites near cemeteries. This had nothing to do with sawmills and cemeteries as such; but unlike sawmills, cemeteries are invariably located on high ground. Much later geologists were able to explain why high ground—particularly hills in otherwise flat country—may indeed be a possible indication of an oil reservoir underneath.

World's Leading Producers of Petroleum

Country	*Annual output in thousands of barrels*
1. UNITED STATES	3,455,368
2. U.S.S.R.	2,995,900
3. SAUDI ARABIA	2,202,049
4. IRAN	1,843,869
5. KUWAIT	1,201,346
6. VENEZUELA	1,178,487
7. LIBYA	819,619
8. EGYPT (U.A.R.)	788,000
9. NIGERIA	665,282
10. CANADA	560,693
11. IRAQ	529,419
12. TRUCIAL STATES	440,132
13. INDONESIA	395,581
14. ALGERIA	384,858
15. CHINA	216,080
16. NEUTRAL ZONE	207,254
17. MEXICO	185,011
18. QATAR	176,545
19. ARGENTINA	158,464
20. ROMANIA	105,296
21. COLOMBIA	71,674
22. BRAZIL	61,088
23. TRINIDAD	51,719
24. WEST GERMANY	51,271
25. CHILE	12,527

Source: U.S. Bureau of Mines, 1972

The next development was more fruitful. Several oilmen realized that experiences in the past might tell them when and where to expect failure or success in the future. They began to jot down every bit of information connected with the search for oil. They instructed drilling crews to keep records. When the drill penetrated a new stratum, the men had to make a note of its distance from the surface, its thickness, the type of rock and whether the rock was dense or porous. They collected records from wells other than their own, and noted geological reports on out-croppings and on some underground structures.

This was the harnessing of science in the search for oil, and the steps were the same as in any other field. First, researchers gather a sufficient number of accurate data. Then they try to organize the material, looking

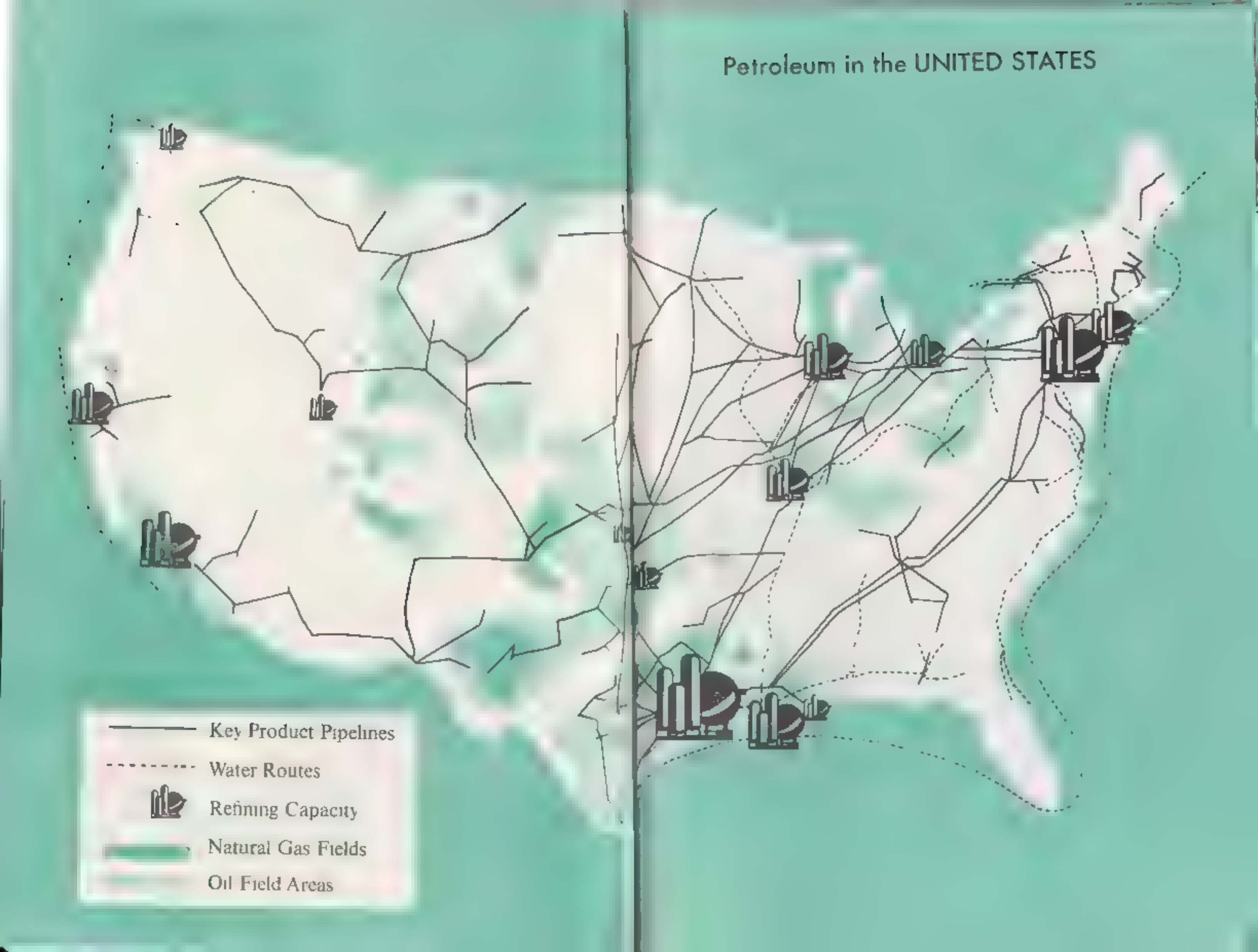
California's first commercial oil well, at Pico Canyon.

2. SURVEYING FOR OIL

The search for new sources of oil has taken this surveyor and his associates to the Pembina area in Alberta, Canada.

for those factors which are most frequently associated with either success or failure. Finally they feel that they might be ready to announce the workings of some law of nature. At this point, they can even venture to make predictions. For instance, when they have learned that in a certain region a layer of sedimentary rock, formed during the Permian Age, has yielded oil in two or three upward curves at a certain depth, they might draw a general conclusion, predicting oil wherever this Permian rock forms an upward curve at that depth.

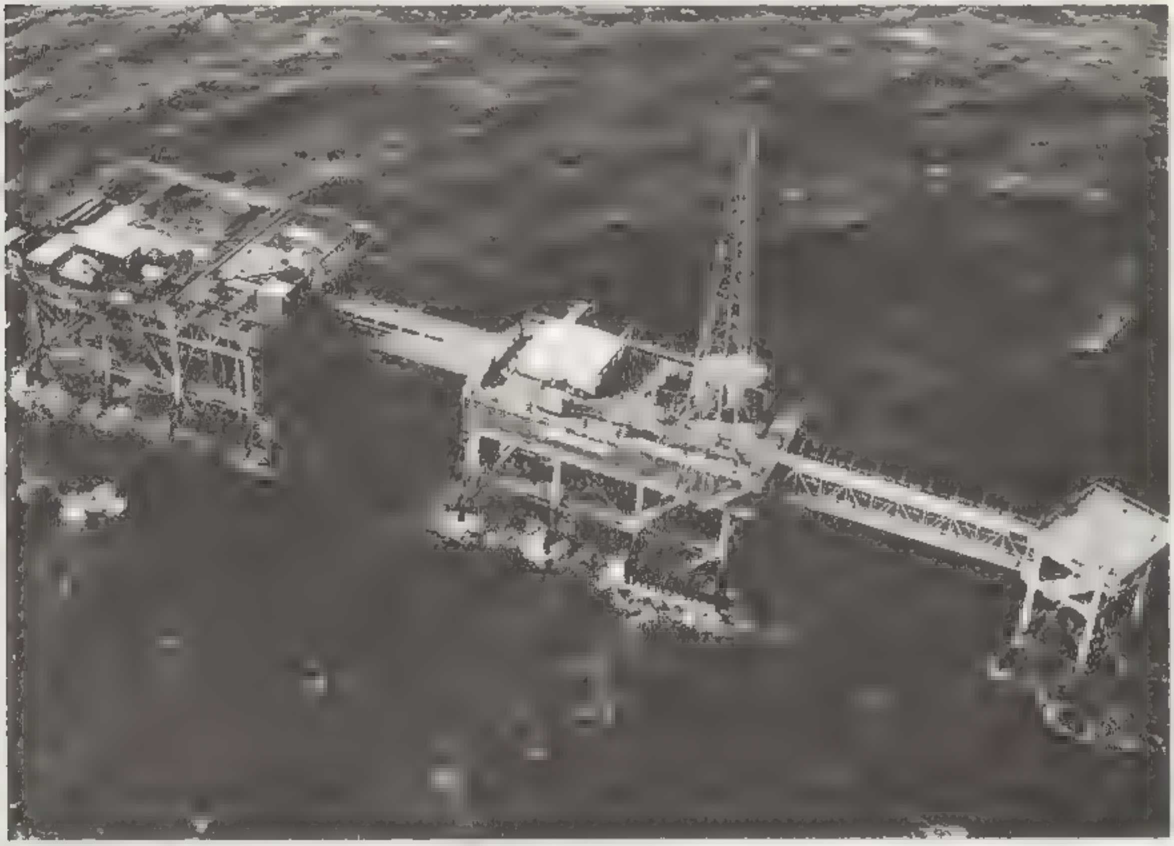
They might be wrong, of course. Maybe they failed to base their predictions on all of the necessary factors. They might have been unaware that this particular formation would yield oil only where the rock in the upward curve is porous and where it is overlaid by dense material. But gradually the petroleum geologists were able to refine their methods.


Petroleum in the UNITED STATES
Key Product Pipelines
Water Routes
Refining Capacity
Natural Gas Fields
Oil Field Areas

Their predictions were becoming more reliable. However, in one respect the geologists were severely limited. They could only gather data where rock formations reached the surface or where wells had been drilled before. At other places the location of oil accumulations within the crust of the earth was beyond their scientific grasp. Even so, surface geology did help discover enormous quantities of oil during the first quarter of this century.

Later the search for petroleum attracted another group of researchers: the geophysicists. They brought to their investigations *seismographs, magnetometers* and *gravimeters*. These tools use principles of physics to obtain information about unseen rock strata.

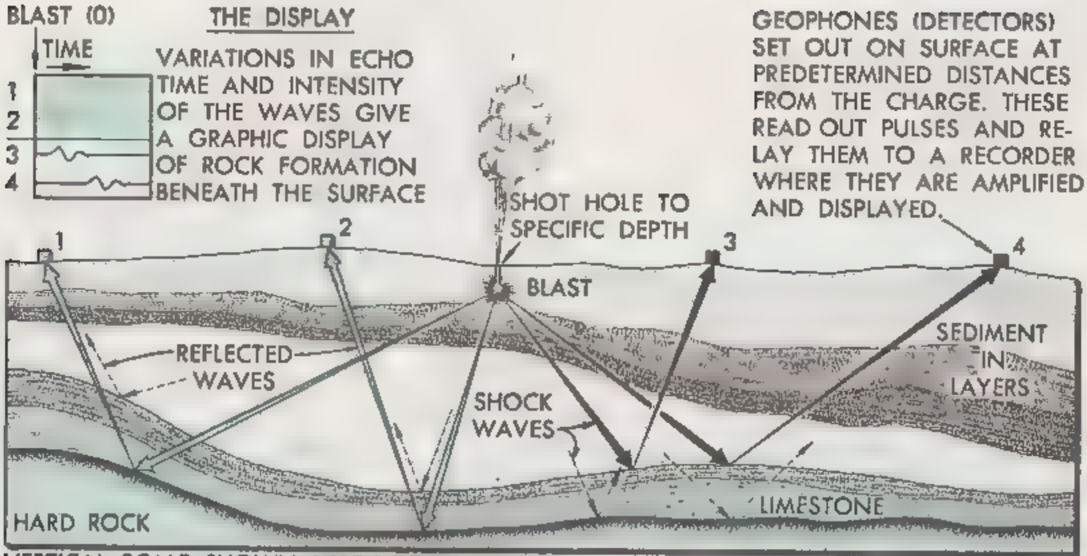
The seismograph used by petroleum geophysicists is an adaptation of the instrument which measures the shock waves made by earthquakes. The difference is that the geophysicist creates an artificial earthquake. The purpose is to measure the speed and intensity of shock waves caused by an explosion.



About 17,000 offshore wells have been drilled in U.S. waters alone, mostly off the California coast and in the Gulf of Mexico. There may be as much as 200 billion barrels of crude oil on the U.S. outer continental shelf.

A member of a petroleum exploration crew studies a print of the recordings of a seismic explosion in the Gulf of Mexico.

SEISMIC EXPLORATION



VERTICAL SCALE SHOWN MUCH FORESHORTENED

Somewhere in the area to be investigated, the geophysicist's crew drills a small hole. At the bottom of it a charge of dynamite is exploded. The shock waves are partly reflected by each layer through which they pass; besides, they are bent in the manner of light waves passing through glass or water. At the surface, the returning waves are detected by *geophones*—instruments in which a weight, responding to the waves, moves a coil in a magnetic field. The movements result in electrical impulses. These are amplified and recorded. The time interval between the explosion and the return of the reflected waves shows the depth of the reflecting rock layer. The refracted (bent) waves indicate the thickness and character of each layer of rock by the time required for the waves to pass through it.

When the seismic exploration crew has finished its task, geophysicists analyzing the record may have a good picture, with the aid of high-speed computer techniques, of rocks thousands of feet below the surface.

The magnetometer is used to spot rocks likely to contain oil. This may seem surprising. Oil is not a magnetic material, and the magnetometer, a highly developed magnetic compass, certainly does not react directly to its presence. But while oil does not contain magnetic substances, rock does; and the proportion of magnetic materials varies according to the

type of rock. Sandstone, limestone and other sedimentary rocks have only small amounts of magnetic materials. Basement rocks have much higher concentrations.

To measure the differences, the magnetometer is attached by a cable to a low-flying airplane. The plane flies back and forth along a plotted path. Up-to-date versions of the recording instruments are synchronized with a camera which takes pictures as the magnetometer measures. The magnetic graph shows the magnetic intensity of the rocks below. The photographs show exactly where the rocks are. These are, of course, the basement rocks which do not generally contain oil. The magnetometer determines their depth and their slope.

The gravimeter solves the same problem by yet a third method. It measures the force of gravity. This force varies slightly according to the

Oilmen operate a gravimeter to measure the rock density beneath them.

density of the rocks underneath. Again, the recorded values provide the geophysicist with important clues to the types of underground formation.

Some of the practical results are impressive. The discovery of the so-called "salt domes" is a case in point.

There was no large-scale exploitation of salt domes until the discovery of the Spindletop well (1901). Salt domes are huge bubbles of salt, a mile or a few miles wide, sitting on top of salt stalks and reaching down into depths that have never been probed. The prevailing theory is that they all stem from a "mother salt", a salt bed maybe 5,000 or 10,000 feet thick whose surface probably lies at a depth of about 30,000 feet or even lower. Some salt bubbles seem to have been pinched off from the mother salt. How the colossal deposits could accumulate is not fully understood. They may have been formed under conditions similar to those in the Dead Sea today.

Wherever the salt found weak spots in the overlying sedimentary rocks, it pushed upward, breaking through and tilting the lower beds and sometimes bending the upper ones into a series of arches. The upward movement of the salt through overlying sedimentary layers is caused by several factors, one of which is its buoyancy—its specific gravity is usually less than that of the sedimentary rock layers.

As the salt plug kept rising, oil moved with it along its flanks until it was stopped by non-porous rocks in the arched layers. Many salt plugs eventually reached the surface (where they may now be hidden under a thin cover of soil). They are called "piercement" type domes. Some are recognizable to the trained eye by the hills they have raised in otherwise level country. Many others got stuck underground. Their upward movement probably could not keep up with the weight of sediment deposits building up on top of them. These are the "deep-seated" domes. Their tops may be thousands of feet under the surface. Nothing above would indicate the presence of the titanic salt bubbles below. Yet they, too, are magnificent structures for accumulation of oil. Their flanks may hold just as much oil as those of the best-known piercement salt dome, the famous Spindletop in Texas, where the Lucas No. 1 well came in on 10 January, 1901, spouting 75,000 to 100,000 barrels of oil a day, and where at one time 132 different companies were drilling next to one another.

The list of tools used in the search for oil is growing. *Scintillometers* and *gas chromatographs* are only two of the more recently developed

instruments. Microscopes are used extensively. Through them the paleontologists study fossil micro-organisms brought to the surface with drill cuttings. The presence of certain micro-organisms might be an indication of places where oil finds are likely. Scientists investigate fossil plant pollen for similar reasons. Donning skin divers' outfits, others search the bottom of coastal waters for shells and other marine animals. Experts pore over graphs made by instruments inside the well—instruments designed to measure the electric conductivity and other properties of the layers through which the drill is passing.

Even bacteria play a part in the search for oil. Certain bacteria thrive on methane. Rising from great depths, this gas can penetrate through

A seismic depth charge sends a spout rising from the deep waters of the Gulf of Mexico. The shot was fired from a seismographic vessel in the continuous offshore search for new sources of petroleum and gas reserves.

3. SEISMIC DEPTH CHARGE

Two "roughnecks" examine the sharp end of a bit used in drilling at a West Texas field.

many kinds of rocks to reach the surface. An analysis of soil samples and of the microflora in springs sometimes indicates the presence of methane and the likelihood of heavier—liquid—hydrocarbons below. Escaping methane does more than provide bacteria with food. It often interferes with the exchange of ions between elements and their radioactive isotopes so that their radioactivity is lower where there is methane.

And where there is methane, there is oil—maybe.

A Risky Business

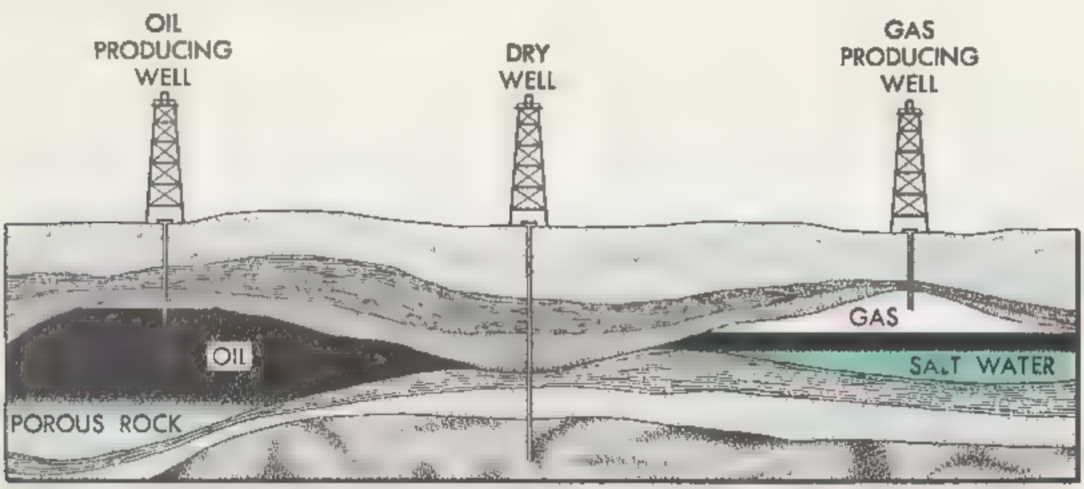
MAYBE IS AN IMPORTANT WORD in any discussion about the search for oil. Magnetometer, seismograph, the study of surface and subsurface geology and the most careful analysis of scientific data can only indicate a degree of probability. Even if every graph and every test promises an oil find, only the drill can tell whether the liquid hydrocarbons are present in commercial quantities, or whether the result will be "suitcase rock", the kind of rock below which no oil has ever been found, and the best thing an oilman can do is pack his suitcase and try some other place. "Oil is where you find it," is a common saying among oilmen. In the search for oil, too, the proof of the pudding is the eating.

The formation that seemed so promising may have collected no oil at all. Or maybe oil was there once but it moved.

Yet oilmen realize that they are more dependent than ever before on the most sophisticated instruments and the most sensitive methods of detection. Probably most of the easily accessible oil accumulations in the United States have been discovered and the obviously recognizable geological structures have been drilled. As Frederic H. Lahee, one of America's best-known petroleum geologists, once put it, "Improvements in the technique of finding have been approximately balanced by the increasing difficulty of locating commercial underground accumulations of oil . . . and this increasing difficulty is dependent mainly on the greater depths of drilling to find new reserves. . . ." Which is another way of saying, "It will cost you about $2 million to drill a 25,000-foot hole, and you will need all the scientific help you can get. Even then you can't be sure that you'll get back a single penny of your investment."

The chances of finding oil vary sharply with the location. The statistics are somewhat on the melancholy side. On one end of the scale are wells drilled in known fields that have already yielded oil. They are the so-called field-development wells. But even here there is no guarantee of success and one out of every four of these wells turns out to be a "dry hole" or "duster". On the other end are the "new-field wildcat" wells—exploratory holes drilled far from known underground conditions in an

TYPICAL DRILLING RESULTS



EVEN IN A PROVEN FIELD WELLS ARE OFTEN DRY. SOMETIMES THEY PRODUCE NOTHING BUT VALUELESS SALT WATER. DRILLING A WELL IS THE ONLY WAY TO BE SURE WHAT IS BELOW THE GROUND.

4. PORTABLE DRILLING RIG

A portable drilling rig is about to be hoisted upright. Resting horizontally, it can be wheeled easily from one drilling site to another.

effort to discover new oil fields. In this group the chance of success is slim. Eight out of every nine attempts will fail. Even among the others some will have to be abandoned within a year so that the rate of attrition is close to ninety per cent. Only three out of one hundred produce enough oil or gas to be called commercially successful. In recent years some 6,000 new-field wildcats have been drilled annually. The cost of each drilling may range from $50,000 up to several millions.

(*Right*) A gusher at an Oklahoma City field in the 1930s. Such inefficient waste of oil is regarded today as bad workmanship and almost never occurs.

Tapping the Earth's Riches

TODAY, MOST WELLS are drilled by the rotary method. A drill bit is attached to the lower end of connected lengths of steel pipe and this drill pipe is revolved by a turntable on the derrick floor. New lengths of pipe are added from above. Meanwhile the drill bit, cooled and lubricated by a special compound called "drilling mud", keeps grinding down. The mud flushes rock fragments to the surface and cakes the walls to prevent collapse or crumbling.

Eventually the drill bit dulls. This may happen after a few feet or a few thousand feet, depending on the hardness of the rock. Then the whole length of drill pipe has to be pulled up and the bit replaced. At extreme depths this "round-trip" may take many hours, as it did in the 25,340-foot well drilled in Texas in 1959. The well established a new world record at that time, but was found to be dry.

When the drill reaches an oil-bearing layer, the oil often flows out by itself. The natural pressure of gas or water will furnish the energy to drive it to the surface. According to an old misconception, the tangible sign of success is a "gusher", a fountain of petroleum spouting from the well. But gushers, common enough in the early days of the oil industry, are undesirable and dangerous. They waste oil and create an immense fire hazard. Every effort is made to prevent them by installing heavy control-valve fittings directly under the derrick floor. Today gushers are rare. They are caused by failure of the control equipment, or by failure of the drilling crew to use the equipment in time.

After a while the pressure of water or gas is spent and the "flush" well turns into a "settled" well. Oil is still there, but now it must be removed by pumping. (Some wells must be pumped from the start.) This stage, too, will pass. Even pumping now fails to produce sufficient quantities of oil, and the well passes into the *stripper stage* of production. A stripper well is generally classified as one with an average daily production of less than ten barrels—produced by the use of pumping techniques.

At this point the life history of an oil well usually came to an end. Although only twenty-five per cent of the oil in the reservoir may have been extracted, no amount of pumping would unlock the other seventy-five per cent. It was then that the idea of "secondary recovery" was conceived—the application of methods which would force most of the remaining oil out of the ground. This development came into prominence in the 1930s.

The first two methods were man-made copies of natural conditions. Since gas or water pressure had driven the oil to the surface in the first

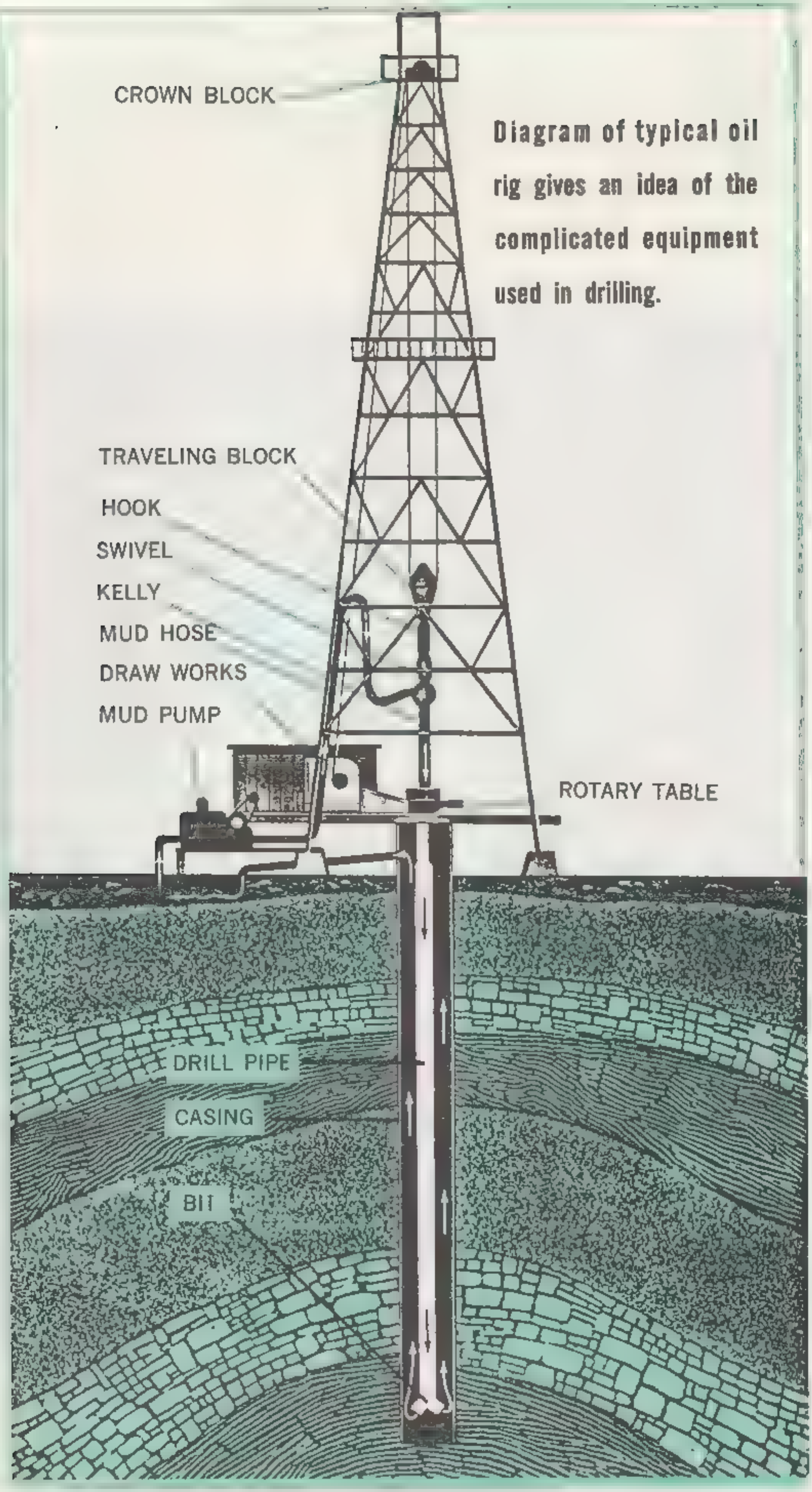
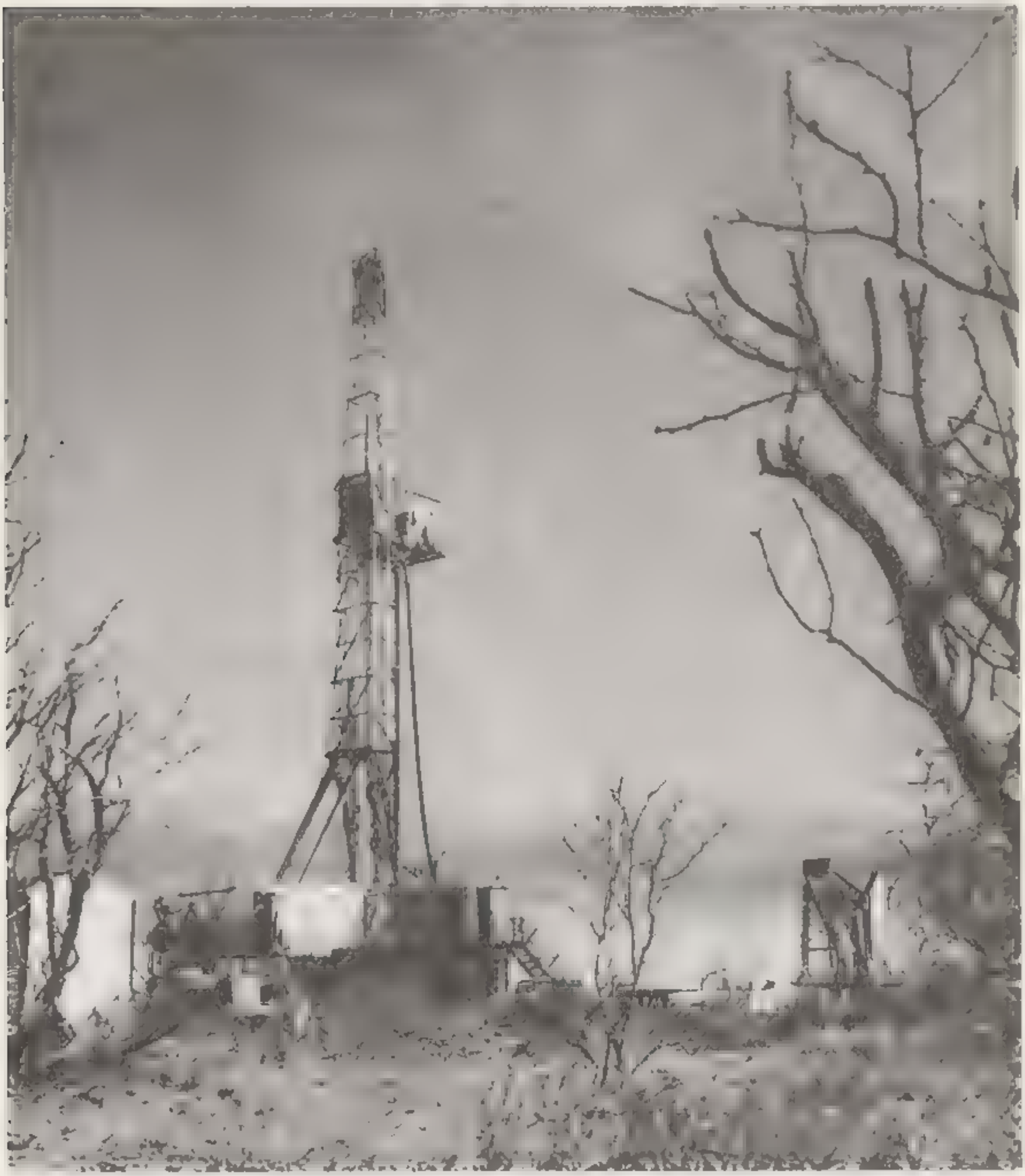


Diagram of typical oil rig gives an idea of the complicated equipment used in drilling.

place, this pressure was now artificially restored. Injection holes were drilled at some distance from the well and through them millions of barrels of water or large amounts of gas were forced down into the formation. The result was more pressure. The oil started flowing again. If



An early rig.

Science Bulletin

Prepared by SCIENCE SERVICE

A COLD PIPELINE FOR ALASKAN OIL?

A Stanford University engineer has developed a system for transporting Alaskan oil that, he says, could minimize the ecological threat to the Alaskan environment, do the job more economically than other proposed systems and would require no new legislation, unlike other systems.

Sullivan S. Marsden of Stanford's School of Earth Sciences proposes suspending the oil of Alaska's great North Slope fields in a frigid brine that could flow in buried pipes without melting the surrounding permafrost, the permanently frozen layer beneath the surface.

One of the main concerns expressed by environmentalists about presently conceived plans for the Alaska pipeline has been the necessity of keeping the oil hot enough to flow readily. This heating requires installation above ground and considerable auxiliary equipment, all of which could threaten the fragile arctic ecology. Rather than thawing the permafrost, Marsden's "cold dispersion pipeline system" would tend to keep it frozen and stabilized.

Aside from ecological considerations, Marsden says, the cold pipeline would be more economical than the hot, involving only refrigeration units to chill the brine-oil mixture while passing through permafrost terrain. Natural gas could also be transported in the same pipe, he says, unlike the hot-oil system, which requires a separate line for gas. Further, he claims, the system should be more impervious to possible earthquake damage and could be built within the twenty-five-foot right-of-way limits now prescribed by law.

USING POWER-PLANT HEAT IN CITIES

University of California researchers A. B. Makhijani and A. J. Lichtenberg claim that energy-conservation practices could reduce the per capita energy consumption in the nation by sixty-two per cent of current levels without damaging our standard of living. Power plants are particularly great energy wasters, with fossil-fuel plants having an efficiency of only around forty per cent in their utilization of heat produced.

Sam E. Beall of Oak Ridge National Laboratory reported on work completed by him and Arthur J. Miller. It suggests that much of the now wasted heat from power plants could economically be used to heat greenhouses and apartment buildings in cities. There are two ways in which this can be done: The use of the relatively low-temperature cooling waters from plant condensers and the removal of partly exhausted higher-temperature steam directly from turbines.

A hypothetical new city with a temperate climate was designed around a power plant capable of supplying electricity to about 390,000 people. Industrial consumers of low-temperature heat and 200 acres of greenhouses near the power plant would use condenser cooling water. Three-hundred-degree turbine steam would be piped to residential and commercial areas for heating as far as twelve miles from the plant.

HYDROCARBON POLLUTION FROM REFUELING

Air pollution control officials have concentrated on ways of curbing hydrocarbon vapor emissions from automobiles and from large stationary sources, such as refineries. Relatively neglected as a source of hydrocarbons—which are key components of smog—are gasoline filling stations.

The Coordinating Research Council reports after a study evidence that a 1972 car releases more hydrocarbons into the atmosphere while its tank is being filled than while it is burning a gallon of gas along the open highway.

The study indicates that an average of 4.7 grams of hydrocarbons are emitted for each gallon of gas pumped into the tank of the average car. With an average filling of 11.5 gallons, 55.6 grams of hydrocarbons are released, almost all of it in the form of vapors in the tank displaced by the filling operation.

LEAD LEVELS IN HAIR

Concentrations of lead in the atmosphere have risen steadily since 1940, says the National Academy of Sciences.

Even so, human absorption of environmental lead may have decreased significantly in the past fifty years according to a report by Donald Weiss of Newton, Pennsylvania, and Bert Whitten and David Leddy of Michigan Technological University in Houghton, Michigan. Their research is based on comparisons of the lead content of antique and contemporary samples of human hair. The presence of lead in the hair reflects the content of lead in the blood because during its growth the emerging hair accumulates and retains heavy metals such as lead.

Samples of old hair contributed by museums and individuals dating between 1871 and 1923 (the year tetraethyl lead was introduced into gasoline) and contemporary hair samples collected from both rural and urban barber shops were analyzed. The researchers found the amount of lead in antique hair to be as much as ten times the amount in contemporary samples—both rural and urban.

These results may seem surprising; in recent years much of the emphasis on lead pollution has been focused on getting the lead out of gasoline and thus out of the air.

But, in fact, the amount of lead absorbed through the lungs by breathing polluted air is minor compared with the amount of lead ingested through the stomach by eating lead-based paint. The use of lead in interior paints was largely discontinued by 1950. Similarly, water is no longer collected from lead roofing nor

stored in leaded jugs as it was in the early part of the century. Lead-glazed pottery, lead toothpaste tubes and lead in food and cosmetics are all sources of lead poisoning much more closely monitored now than they were fifty years ago. "Thus," say the researchers, "the lower lead content in human hair in our contemporary population is probably a result of greater precautions in the use of lead in spite of a general increase in atmospheric concentrations."

Still, lead pollution and lead poisoning are problems. Although the effects of lead poisoning resulting from exposure to lead-based paints, such as mental retardation and behavioral difficulties, are known, similar information on the effects of low exposure to lead is not available. There is a definite need for research in this area.

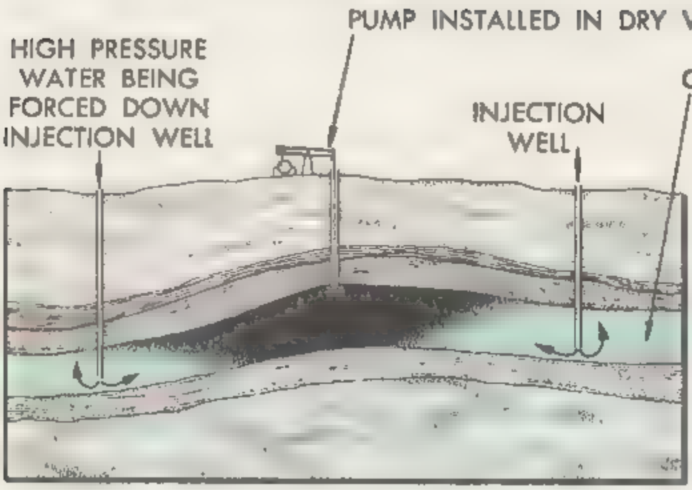
AFTER THE OIL SPILL

Chemist Max Blumer of Woods Hole Oceanographic Institution is probably the pioneer in studies of long-term effects of oil spills. He has done detailed analyses of the 1969 West Falmouth, Massachusetts, marine oil spill for three years.

Blumer reports that in one sense the work is encouraging. For the most part organisms have been able to resettle in the spill area. Hydrocarbons have either been degraded or have decreased in toxicity due to bacterial attack, evaporation, dispersion and chemical attack.

On the other hand, the oil that actually entered organisms persists throughout their lifetimes and probably into the following generations. Likewise, the hydrocarbons still remaining in West Falmouth Bay will continue to enter life forms and the marine food chain.

WATER FLOODING



OLD WELLS THAT HAVE STOPPED PRODUCING AND NEW ONES WHERE OPTIMUM YIELD IS BEING ATTEMPTED MAY USE WATER FLOODING. WATER AT HIGH PRESSURE IS FORCED INTO THE PRODUCING FORMATION THROUGH INJECTION WELLS AROUND THE PUMPING WELL. THE WATER FORCES THE OIL TOWARD THE PUMPING WELL. OIL AND WATER ARE RECOVERED AND LATER SEPARATED.

conditions were right—and they could be made right in various ways, for instance by fracturing the formation—up to eighty per cent of the oil could be extracted.

Sometimes these methods are unsuitable or they are not quite as efficient as had been hoped. But scientists have come up with many new ideas, some of them just as dramatic as the results they have produced. The *fire drive* might serve as an example. By this method the energy required for moving the oil toward the producing well is provided by injecting air or another oxygen-bearing gas into the reservoir and burning a portion of crude oil. Ahead of the slowly advancing fire, coke is formed. Ahead of the coke is a zone of hot water and hot oil. The heat thins the oil and makes it free-flowing. At the same time, it creates pressure that will drive the oil toward the well. There now are at least five fire drive, or thermal, methods. Laboratory tests show that one or another might wring close to ninety per cent of the oil from the rock.

Other new methods achieve equally far-reaching results. Even the most carefully controlled gas or water drive will not dislodge all of the oil because the gas or water has a tendency to flow through the larger openings. Many cracks and pores are bypassed, and the capillary forces within them retain tiny oil globules. One way of overcoming these forces is to pump chemicals—for example, liquid propane or butane—into the formation. The chemicals will mix with the oil and make it flow freely even through small passages. In another method, injected water is mixed with carefully regulated amounts of carbon dioxide. When the carbonated wa-

ter encounters the crude oil, it reacts with certain hydrocarbons to form chemicals that serve as a detergent to wash the oil out of the rock and speed it toward the surface at the production wellhead. This method, too, may push recovery up to ninety per cent.

Perhaps the results can be still further improved. Scientists believe that some day hardly any petroleum in a formation need be abandoned. Petroleum is too valuable to be wasted.

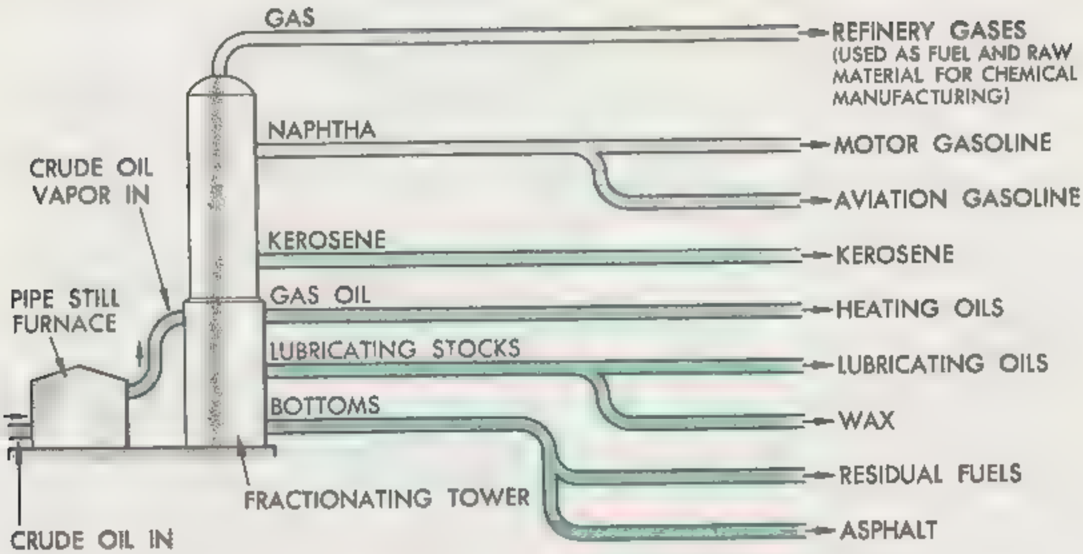
The Magic of Refining

THREE-QUARTERS OF ALL ENERGY consumed in the United States is provided by petroleum and its chemical kin, natural gas. Besides, petroleum is the source of a vast number of products from insecticides to nylon. But since petroleum is a very complex mixture of hydrocarbons, it

A giant mobile drilling rig, Mr. Gus II, stands in 137 feet of water in the Gulf of Mexico. By 1973, there were about 17,000 offshore wells in the United States.

5. OFFSHORE DRILLING

FRACTIONATION



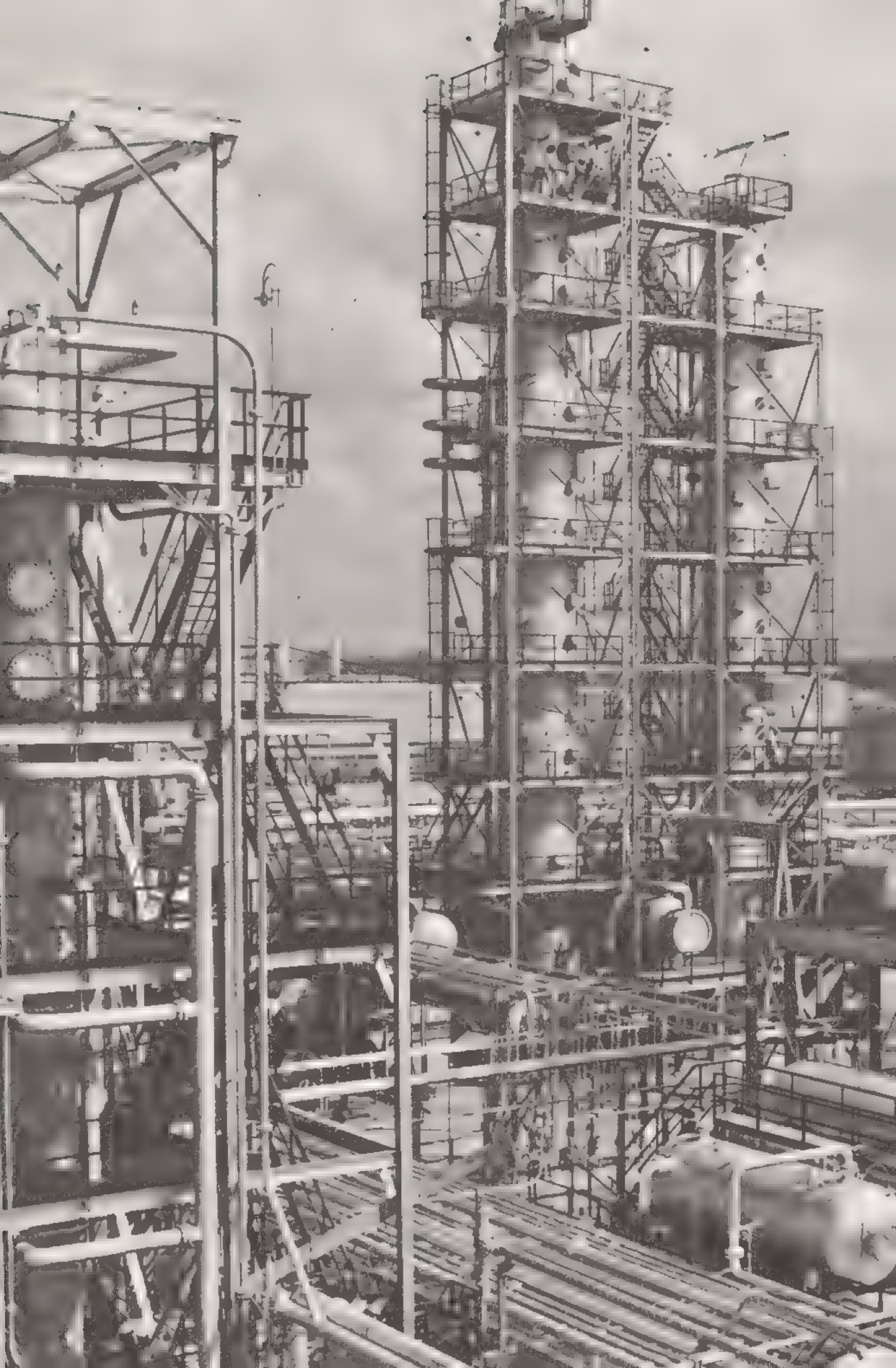
is necessary to separate the hydrocarbon groups from one another before they are used. The molecules that furnish the energy for an automobile engine are not the same as those that go into the making of plastic foam. Asphalt has a molecular structure unlike that of a hand lotion.

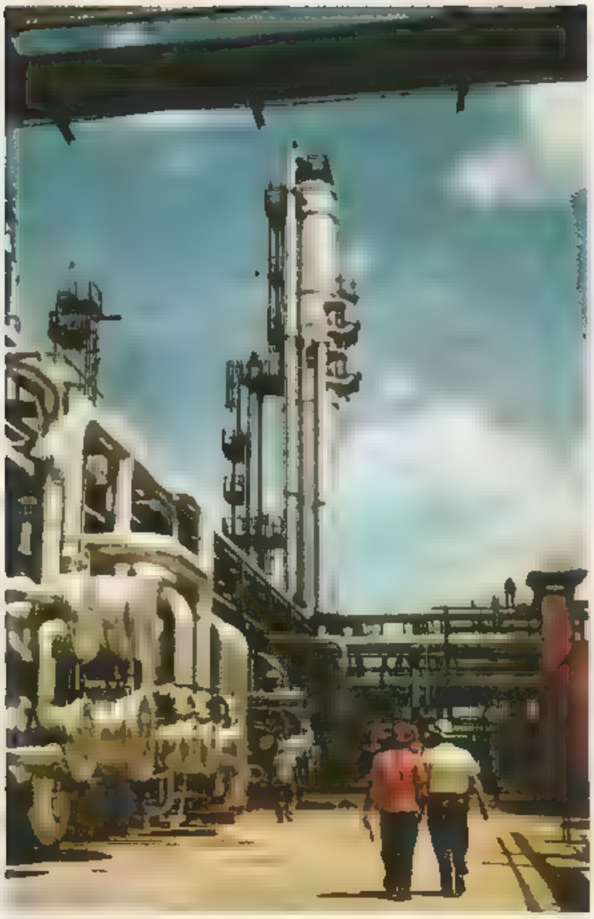
Hydrocarbons are first separated by *distillation*. Since they have different boiling points, they will turn into vapor at different temperatures. The ones with the lowest boiling points will vaporize first. This process usually takes place in a heating device connected to a *fractionation* or "bubble" tower.

Before entering a fractionation tower, the petroleum is heated so that it turns into a mixture of hot vapors and liquid. Then it goes into the tower—a vertical column with many subdivisions which give it a superficial resemblance to a skyscraper. The column may be a hundred feet high.

Residue is drawn off at the bottom of the tower. It will later be used as asphalt or as heavy fuel. As other oil fractions rise and cool, they condense, arranging themselves along the height of the tower according to

(*Following pages*) Not a plumber's nightmare, but three of the basic units found in a typical refinery.





This is one unit in a petrochemical plant where a variety of products are manufactured, including anhydrous ammonia, high purity ethylene, ethylene dioxide and glycol. These are extracted from what was once petroleum.

6. CHEMICALS FROM PETROLEUM

their boiling ranges. The fractions with low boiling points—gasoline is one of them—collect at the top.

Wherever fractions condense, they can be withdrawn from the tower. Some fractions have such a low boiling range that they remain uncondensed. These are piped as gas from the tower's top.

Distillation is not enough. For one thing, it only separates the crude oil into fractions which in themselves are made up of so many substances that they have to undergo further separation. For another, the proportions of those substances do not always coincide with the demands for special petroleum products. For instance, distillation and fractionation produce rather small amounts of gasoline.

Petroleum scientists have learned to overcome this difficulty by "cracking" molecules. In *thermal cracking,* high temperatures are applied under

increased pressure. This puts a strain on the forces holding the molecules together and some of them break. Larger molecules are thus cracked into smaller molecules, and these will rise to their proper levels in a fractionation tower.

This is the method by which great quantities of gasoline are made from heavier hydrocarbons. But the cracked product is not identical with the "straight-run" gasoline. Its atoms are arranged in a slightly different manner which happens to yield a gasoline of higher quality with better antiknock characteristics.

The strange expression "cat cracking" refers to a cracking process in which a *catalyst* such as alumina is used. A catalyst is a substance which

More refineries, like this one in England, must be constructed if the petroleum industry is to meet the ever-increasing worldwide demand for energy.

causes or accelerates chemical reactions without actively taking part in them. Again, the result is the breaking-up of heavier hydrocarbons; but this is now accomplished at lower temperatures. The newly created smaller molecules are an even greater improvement on the straight-run gasoline.

But just as large molecules can be broken up, small molecules can be combined to make larger ones. The preferred method is *polymerization*. It consists of joining together several light gaseous hydrocarbons to build

Constant laboratory research is a vital part of every oil company's operation. Scientists are always looking for new uses for petroleum.

WHAT A BARREL OF CRUDE OIL YIELDS

1920

GALLONS PER BARREL		PER CENT YIELD
GASOLINE	11	26
KEROSENE	5	13
GAS OIL AND DISTILLATES; RESIDUAL FUEL OILS	21	49
OTHER PRODUCTS AND LOSS	5	12
TOTALS	42	100

TODAY

PER CENT YIELD	GALLONS PER BARREL	
46	19	GASOLINE
7	3	JET FUEL
24	10	GAS OIL AND DISTILLATES
7	3	RESIDUAL FUEL OILS
16	7	OTHER PRODUCTS AND LOSS
100	42	TOTALS

a hydrocarbon of a heavier structure. Again, the result may be more gasoline. But this time it is gasoline made of gas.

Several other processes have been developed to juggle the atoms in hydrocarbons and to produce substances with tailor-made characteristics. For example, atoms can now be rearranged so that they duplicate the long chains of giant molecules of which rubber consists. The result resembles natural rubber without some of its faults.

Improved refining techniques have increased the yield of those products which are in greatest demand. For instance, in 1918, a barrel of petroleum would yield about ten and one-half gallons of gasoline. A barrel now yields over nineteen gallons—and the gasoline is much better.

Moving the Oil to Market

CORSICANA, TEXAS, is one of a small number of small communities in the United States where oil pumps can be seen—and heard—in people's gardens and next to schools and churches. Oil recovery is on the scale of a home industry.

To own an oil well in the backyard is, of course, an exception. Most people live at far greater distances from the source of petroleum. Mere distance, however, has little bearing on their ability to use oil and its products. There are many ways in which the oil can reach them.

All oil flow begins at the well. Once out of the ground, oil is first stored in tanks. This sounds simple enough, although economic and technologi-

9. LAYING A PIPELINE

Here a "boom cat" lays a twenty-six-inch pipeline to add to the vast network of crude-oil lines and product lines that criss-cross the United States. Today, pipelines with diameters of more than three feet are not uncommon.

cal problems can be quite formidable. When an offshore oil well in the Gulf of Mexico produces oil from a hole drilled into the bottom of the sea a dozen miles from the nearest land, conventional storage in tanks is out of the question. Oil tankers or barges must take over. More and more, pipelines can be strung from a marine well across several miles of ocean to a storage facility on land. Another solution, still in the experimental stage, seems to be particularly attractive: giant tanks with a capacity of many thousands of barrels are to be anchored on the sea bottom. Unlike the familiar metal tanks on land, the underwater containers would occupy no valuable real estate.

For natural gas, LP gas (liquified petroleum gas) and refined products, many other types of storage facilities have been used. Sometimes a stone quarry is convenient, provided that its bottom and walls are impervious. Several companies have "dug" storage tanks by hollowing out salt domes with water.

But to return to the crude oil. After leaving the well site it will eventually reach one of the main crude-oil trunk lines, either through so-called gathering lines (small diameter pipelines), or trucks or barges. Its first major destination usually is a crude-oil terminal, a place where specific instructions for shipping and usage determine the oil's itinerary and fate. Eventually all of it will pass through a refinery, but after it reaches the terminal, the flow is divided. Part of the oil may be directed to a nearby refinery to be processed into gasoline, heating oil and a host of other products. Another part may have to move on for hundreds of miles before it reaches a refinery. After the crude oil has been refined, product pipe-

Some 3,600 tankers ply the world's oceans delivering oil at the rate of about 30 million barrels daily.

8. SUPERTANKER UNDERGOING SEA TRIALS

A supertanker is shown above on a test run shortly after completion. She can carry 25,641,000 gallons—enough to keep a good many motorists' tanks full for a long, long time.

lines may take over and continue the oil's journey from the well to the consumer.

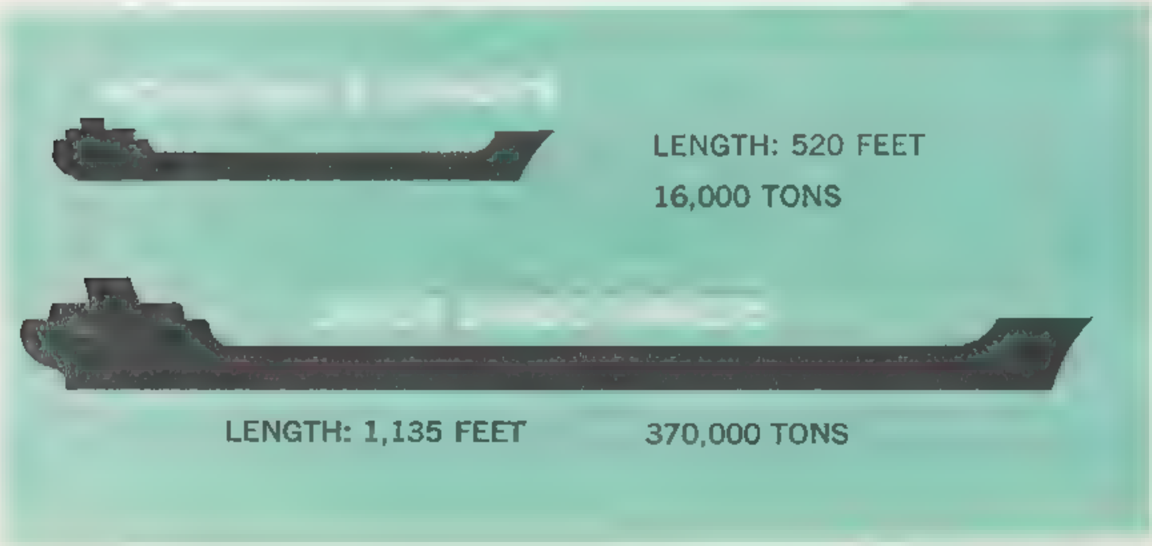
At various stages during the oil's progress other forms of oil transport may be used: tankers, railway tank cars, barges and tank trucks. The tank trucks probably are most familiar to people, because trucks usually take over when the refined products are about to reach final distribution points or the ultimate consumer. Tank trucks deliver gasoline to more than 211,000 gasoline service stations and heating oil to millions of homes. The owners of some 100 million automobiles and millions of home owners have tended to take the miracle of distribution for granted and most have gone through life until recently without ever seeing the sign, "Sorry—no gas

today," or living in an unheated house. But there have been and still may be shortages of both gas and heating fuel in parts of the country, particularly in California where there are more cars than in any other state, and during the cold winters in New England and the Midwest. These shortages result from the ever-increasing demand for energy by Americans.

Tankers come in all sizes, from the smallest—which have a displacement of a few thousand tons—up to the supertankers of more than 500,000 tons which were scheduled to join the world fleet of 3,600 tankers. With a total of 190.5 million deadweight tons, that fleet transports some 30 million barrels of oil daily through the oceans and seas which cover seventy-one per cent of the earth's surface.

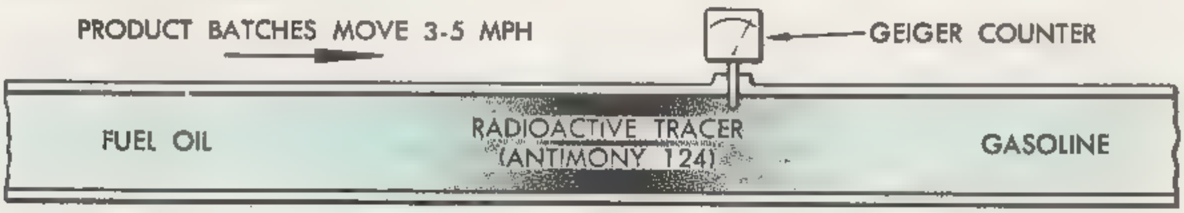
The tanker fleet will continue to grow as the demand for oil increases to meet the energy demand throughout the world, especially in the United States, which by 1980 will get about thirty per cent of its oil through the Persian Gulf. The chances of oil spills into the oceans increases as more and more oil is transported over great distances. The oil industry has stepped up its efforts to reduce such discharges—which could threaten marine life—through better ship design, improved operations and loading equipment.

Today, most oil moves across the United States through a network of 218,000 miles of pipelines—11,000 miles more than the total railroad track. At one end crude oil or an oil product is fed into the line. Pump pressure keeps the liquid flowing until it reaches the refinery or distributor. One pipeline carries petroleum products from Houston, Texas, to Linden, New Jersey—a distance of 1,600 miles.



In a pipeline, the flow has to be continuous. In a products line, batches of different products are kept apart. Gasoline may be preceded by diesel oil and followed by kerosene. Commingling—contamination of one by the other—has to be kept to a minimum. At any distribution or delivery station along the line the operator should be in a position to know where one batch ends and the next batch begins. As many as thirty batches may follow one another in close succession.

INSIDE A PIPELINE



Several methods have been worked out to locate the *interfaces*—the zones where liquids follow each other and where some commingling is unavoidable. By one method, an electronic probe inserted in the pipeline and a recording instrument at the pumping station make it possible to determine which products are passing through the line by variations in their electrical properties as they react when passing between the electrodes on the probe. Another way of finding the interface is by using a radioactive tracer, such as antimony 124 or strontium 90.

As the products travel along the pipe, the interface and tracers in it will spread out. On arrival near a station a geiger counter picks up clicks whose frequency increases with the approaching peak of the radiation level. The level reaches its maximum at the exact middle of the interface. Here is the best dividing line. If the findings are telemetered to the adjacent station a few miles upstream, the operator knows exactly when to expect the radiation peak and the interface midpoint, and when to throw the switch that will separate the liquids.

Since pipelines are underground for the most part, maintenance and repair create peculiar problems. The job of the maintenance engineer has been compared to that of a doctor in some parts of the Near East who, if the patient is a woman, is permitted to examine her only from the out-

More and more, pipelines can be strung from an offshore well such as this to storage facilities on land. At other times, barges or tankers must be used.

At Miami International Airport, aviation fuels are piped underground from storage area to planes. Here a technician adjusts an aboveground flow valve.

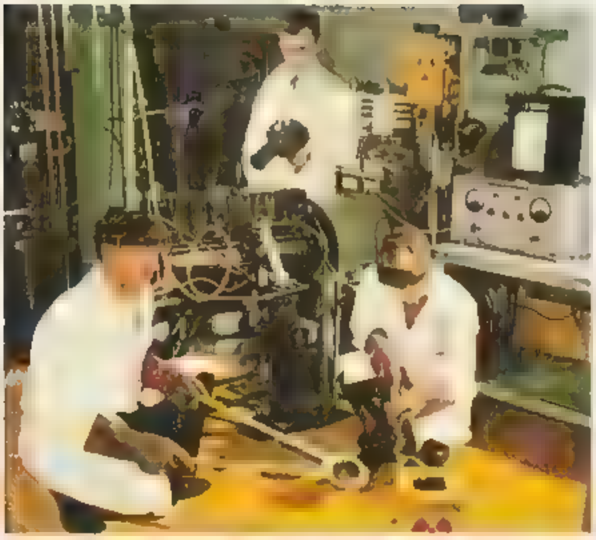
side of the closed tent, while she is inside. Nevertheless he has to make a diagnosis and prescribe a medicine. Pipeline maintenance and repair men also have to make their diagnosis and effect cures from the outside. If the flow in the line is impeded, they send a "go-devil" through it to clean and scrape the walls of the pipe. The go-devil might be described as a mechanical chimneysweep—a device which fits inside the pipe and which is pushed along by the flow of oil. To prevent corrosion, the pipe is given a moisture-resistant coating, and metal bars and other devices are set up to neutralize corrosive electric currents in the ground. Yet corrosion is difficult to fight. The pipeline may still develop a leak.

Spotting a leak in a line leading through wooded or mountainous territory used to be the job of the line walker. Today, inspection is often carried out from low-flying airplanes. Oil leaks may show as dark stains. Even leaks that do not show can be detected if small amounts of radioactive isotopes have been added to the oil. The soil surrounding the leak

(*Left*) Laying a section of the original "Big Inch" pipeline, 1,476 miles long, linking Texas with the Atlantic coast to meet needs in World War II.

This Boeing 747 jet on an average transcontinental flight will burn 200,000 pounds of fuel or 26,316 gallons—one gallon equals 7.6 pounds. It carries about 350 passengers and tons of mail and cargo.

Oil tankers come in all sizes. This is a small one compared to some, displacing more than 500,000 tons, that are coming into service.



10. RADIOACTIVE PISTON RINGS

The effectiveness of lubricating oils in reducing engine wear has been tested by using radioactive piston rings. Here two men, using tongs, rubber gloves and face shields, lift out a new supply of piston rings. In the background a man stands by with a geiger counter.

will give off radiation. The isotopes used for this purpose are short-lived. Their radiation, weak even at the time of injection, will have decayed to a minute fraction of its original strength within a few days.

3,000 Products of Petroleum

BECAUSE PETROLEUM IS OUR PRINCIPAL SOURCE of energy today, most of it is used as fuel. But ultimately its other uses may turn out to be just as important. It has been called a "molecular treasure chest". This somewhat flowery expression has a good basis in fact. The number of different molecules that can be separated or made from crude oil (and natural gas) is probably well over a million. This means that petroleum contains more than a million building blocks for potential new products.

Three thousand petroleum-based products are being made today. Invariably the manufacturing process involves either hydrocarbon molecules alone or hydrocarbon molecules in combination with other chemicals. Sometimes all that has to be done is to take away atoms. This is, for instance, what happens in the manufacture of synthetic rubber. The raw

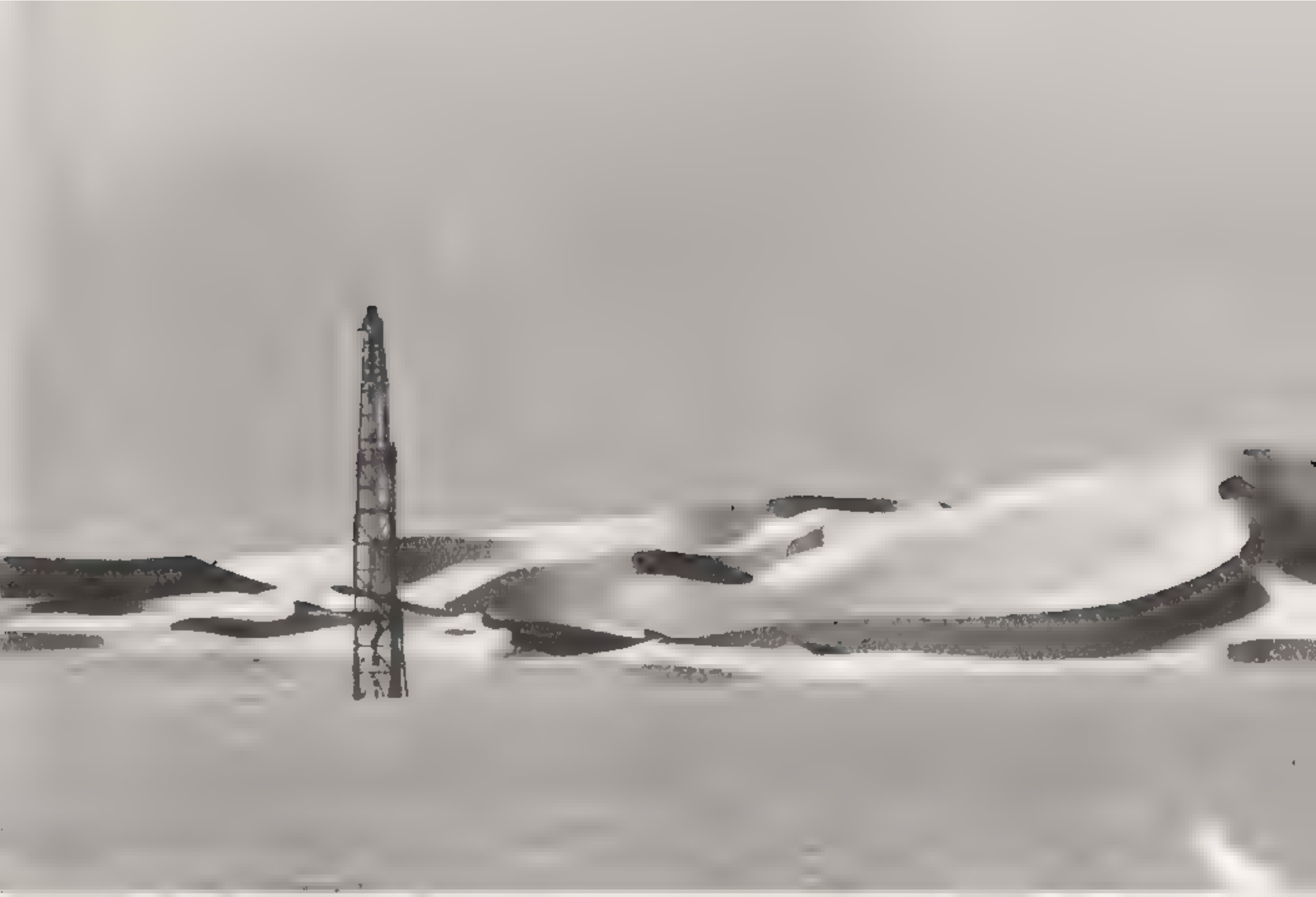
(*Right*) One refinery alone may contain as many as 500 miles of pipeline. On the left are two gas-storage spheres and in the background rises a catalytic cracking unit.

12. FERTILIZERS FROM PETROLEUM

This farmer feeds anhydrous ammonia—a derivative of petroleum—directly from a tank mounted on his tractor to the soil around his crop of corn.

material is a hydrocarbon whose chemical formula is C_4H_8; it is commonly known as butylene. If two hydrogen atoms are removed, the result is butadiene (C_4H_6). Butadiene is the principal raw material used in the manufacture of the Buna-S (or GR-S) type of synthetic rubber from which automobile tires are made. All types of elastoplastics, as synthetic rubbers are more properly called, now account for about seventy-five per cent of the rubber consumption in the United States.

Molecules can be manipulated, so it is possible to produce substances with exactly the qualities needed for a specific job. Usually oil floats on water, but it can be changed so that it will creep under a film of water, lifting it from a metal surface and thus acting as a rust preventive. Usually



Oil from the rich desert fields in the Middle East flows from this well through pipelines into the tankers docked at the island terminal in the Persian Gulf. The tankers carry the crude oil to refineries throughout the world.

oil vapors will burn, but by reshuffling some oil atoms, oil can be made into a fire-retarding agent. Usually oil is thicker at lower temperatures and becomes thinner as it warms, but its viscosity can be stabilized. This, for example, can make the product suitable for planes. Descending from the chilly stratosphere, a plane may land on a hot tropical airfield without fuel complications.

A hundred years ago, machines depended on lubrication as they do today, but the lubricants were different: melted beef tallow for valves, castor oil or lard for bearings. Most of today's lubricants—there are hundreds of them—are derived from oil. They are precision-made to meet special requirements. Some must perform well or insure practically frictionless functioning of satellite or spaceship components jarred by rocket explosions in the absolute-zero environment of space and under conditions of extreme pressure. Others must remain stable in the heat of the tropics or the cold of the Arctic. San Francisco's Golden Gate Bridge is one of several whose suspension cables are impregnated with highly adhesive oil lubricants forming a coating to keep out moisture.

Petroleum is a prime source of alcohols—methyl, ethyl, isopropyl, allyl, butyl and others—some of which go into explosives, antifreeze, medicine, rayon, lacquers or smokeless powder. Detergents and paint solvents are manufactured from petroleum. Lipsticks, hand lotions, perfume and cold

Drilling ships such as this head out to sea in a continuing search for oil and gas—in the rich waters of the Pacific, the Gulf of Mexico, the Persian Gulf, the British North Sea and the Mediterranean.

The S.S. *Manhattan*, a giant icebreaking tanker, became the first commercial ship in history to conquer the legendary Northwest Passage. The specially built 125-foot bow moves the vessel up and over the ice until the weight of the ship breaks through. The 1969 voyage proved the feasibility of transporting Alaska's newly discovered oil to U.S. east coast ports. Note some crew members out on the ice.

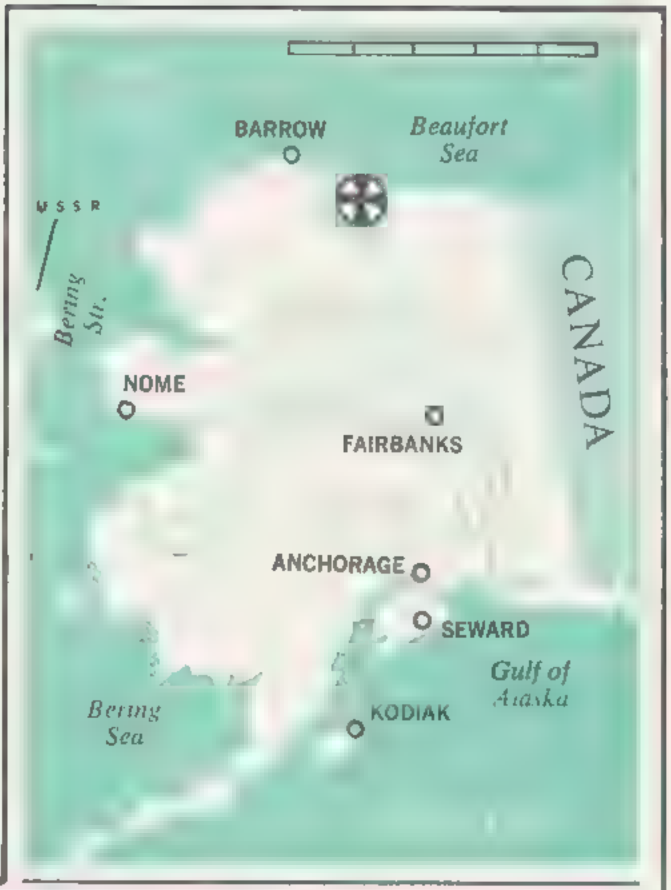
Here at San Juan International Airport, Puerto Rico, fuel is being pumped into a jet airliner from underground pipeline. The hydrant truck has now replaced the tank truck—like the fire engine that need not carry its own water supply.

11. FUELING A JET

cream are either made from oil or contain ingredients derived from it. From oil comes raw material for synthetic fibres such as nylon, and a great many plastics. Oil also is the active ingredient of many agricultural sprays—for insecticides, weed killers, to rid animals of parasites and to help prevent plant disease.

Scientists now are growing proteins from petroleum, a development that eventually may help ease the world's hunger. It turns out that one of the most promising sources of synthetic protein is in microscopic organisms that can be grown on petroleum hydrocarbons. What happens is that the microscopic organisms biochemically change the hydrocarbons into something called "single cell protein". It has been found that while a 1,000-pound steer feeding on grass can "manufacture" about one pound of useful protein a day, 1,000 pounds of the microscopic organisms can produce 2,500 pounds of protein in the same time.

The single-cell protein that is being produced in laboratories is a fine, white powder in its final form, and is bland-tasting and odourless. It mixes well with other foods. The objective over the short run is to produce a food supplement that can be fed to livestock and enrich human diets in a secondary way. The ultimate goal is the development of a single cell protein that can be directly consumed and enjoyed by people.



The great oil strike at North Slope, above the Arctic Circle in Alaska, is marked by a cross.

THE NORTHWEST PASSAGE. The search for a trade route through the Northwest Passage started in 1497 when sailors first sailed wooden ships toward the roof of the world in hopes of finding a route to Asia. The map shows the successful, 4,500-mile passage in September, 1969, of the S.S. *Manhattan*.

Energy Shortages . . . Search Continues

THE SUPPLY OF PETROLEUM is not limitless, and while the world is not running out of oil and gas there is concern that if the current demand continues many nations, especially the United States, will face serious energy shortages over the next several decades. Petroleum provides the world with more than half of its total energy requirements.

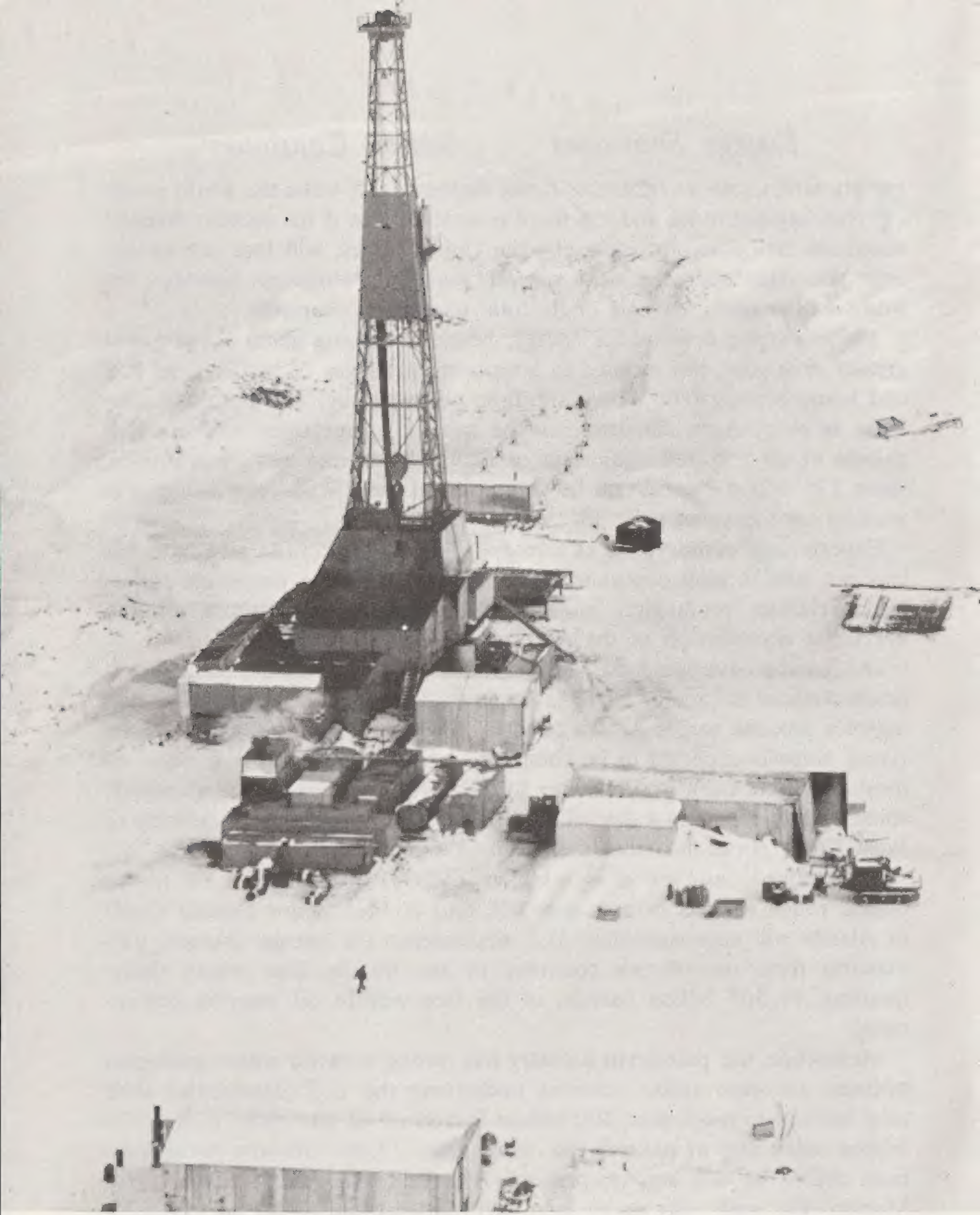
The increasing demand for energy, which is running about six per cent greater each year, has resulted in temporary shortages of gasoline, jet fuel and home heating fuel. These shortages, experts say, will probably continue as every American uses, on the average, some three and one-half gallons of oil and 300 cubic feet of natural gas every day. World-wide, some 235 billion barrels will be consumed in the 1970s—more than was used in all the years prior to 1970.

Experts urge conservation of energy—like driving a little slower to use less gas, and turning out unnecessary lights—while the petroleum industry accelerates production, continuing the search for offshore oil and beginning construction of the Alaskan pipeline.

Delayed by environmental considerations—a delay which petroleum officials contend is a major factor in the overall shortage of energy—the laying of a pipeline across Alaska to tap the billions of barrels of oil on the Arctic slope is expected to be completed by about 1977. It will cover almost 800 miles from Prudhoe Bay to the port of Valdez, where ultimately some 2 million barrels a day will be loaded aboard tankers for delivery to West Coast ports and from there throughout the country.

The proved reserves of 10 billion barrels plus another 30 to 40 billion which experts believe they will find at the "junior Persian Gulf" in Alaska will ease somewhat U.S. dependence on foreign sources, particularly from the oil-rich countries of the Middle East where three-quarters, or 367 billion barrels, of the free world's oil reserves are located.

Meanwhile, the petroleum industry has turned seaward where geologists estimate the recoverable reserves underlying the U.S. continental shelf may amount to more than 200 billion barrels of oil and more than 1,000 trillion cubic feet of natural gas. More than 17,000 offshore wells have been drilled in U.S. waters, primarily off California and in the Gulf of Mexico. The wells may go as deep as 1,500 feet and as far as 165 miles from shore.



Described as a "junior Persian Gulf," oil from Alaska's North Slope hopefully will begin flowing into the "lower forty-eight" states by the late 1970s.

Future Sources of Energy

EXPERTS SEE "good news and bad news" as they assess the potential resources to meet the fast-growing need for energy throughout the world. If the consumer will not waste energy, the good news is that the petroleum industry, the prime source of energy, will be able to meet the demand without serious shortages. The bad news may come later in the 1970s when even with increased imports of oil the supply of petroleum may fall short of the demand by as much as ten per cent.

Petroleum, according to a government study, will continue to be the prime source of energy well into the future, even though some other sources will increase. For example, nuclear power, which has been slow in developing and today supplies less than one per cent of the total U.S. demand, is expected to increase to sixteen per cent by 1990.

Hydroelectric energy is expected to decrease due to availability of dam sites; coal consumption will grow and remain an important source, meeting more than ten per cent of the demand by 1985; synthetic fuels—including oil and gas from coal, and oil from shale—are potential sources in the early 1980s; and natural gas is number two behind petroleum, but its share is expected to decline from one-third today to twenty-one per cent in 1985.

We have been talking pretty much in terms of proved reserves. In the case of crude oil, for example, proved reserves means only the volume which scientific studies indicate is recoverable. Ultimate reserves are much larger than proved reserves. They are estimated to be in the range of up to about 600 billion barrels—more than seven times more than all the petroleum withdrawn from the ground since Colonel Drake drilled his first well more than a hundred years ago.

Technological developments will, of course, be a factor in tapping the underground and offshore reserves—as will the cost. Drilling offshore requires special rigs and vessels that can cost tens of millions of dollars. On land, thermal drills might use extraordinary high temperature sources to disintegrate rocks at a fast rate. Controlled underground atomic explosions are a potential tool for petroleum recovery. Their heat might even be used for underground distillation and fractionation.

You can be sure that the demand for energy will not lessen. So the search must go on to meet the world's vital needs.

Important Dates in the History of Oil

1859	First oil well completed by Edwin L. Drake near Titusville, Pa.
1861	First oil refinery completed near Titusville; cost: $15,000
1865	Two-inch iron pipeline moves crude oil a distance of five miles
1865	Oil shipped by tank car for first time
1866	First Texas oil well completed
1870	First ship fitted for carrying oil sails from New York
1876	First practical four-cycle gas engine is built
1879	Patent applied for an auto driven by internal combustion engine
1885	First gasoline pump delivered
1901	Famed Lucas gusher brought in at Spindletop, Texas
1903	First cross-America automobile trip; time: ten weeks
1903	Wright brothers' flight at Kitty Hawk, North Carolina
1911	First trans-America plane flight; time: seven weeks
1913	Patent issued for first cracking process
1918	First gas pipeline put in operation, running forty miles
1919	First practical oil burner for home heating
1923	Ethylized anti-knock gasoline developed
1930	Construction started on first long-distance pipeline, Texas to Illinois
1936	First successful use of water flooding for secondary recovery of oil
1937	First patent for butyl rubber
1942	"Big Inch" war emergency pipeline started
1945	First sale of lease, by Louisiana, for offshore oil exploration
1957	Record for exploratory drilling—14,707 wells in a year
1968	Largest petroleum field discovered in Western Hemisphere; located 260 miles above Arctic Circle in Alaska, region may yield 50 billion barrels
1971	*Nisseki Maru* (372,500 tons), the world's largest oil tanker, goes into service
1972	First oil well below 30,000 feet drilled in Oklahoma
1973	New record-size oil tanker (477,000 tons) under construction in Japan; orders placed in France for two tankers at 540,000 tons

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